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PART II

DRAFT INTERIM TEST RESULTS REPORT FOR BIOVENTING TEST WORK PLAN FOR FIRE TRAINING PIT 1 AND SPILL SITE 1 F.E. WARREN AFB, WYOMING

Prepared For

Air Force Center for Environmental Excellence
Brooks AFB, Texas
and
90th Support Group/DEVR
F.E. Warren AFB, Wyoming

ES ENGINEERING-SCIENCE

ES
Engineering-Science, Inc.
1700 BROADWAY, SUITE 900
DENVER, COLORADO 80290

August 1992

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PART II
DRAFT INTERIM TEST RESULTS REPORT FOR FIRE TRAINING PIT 1 AND SPILL SITE 1
F.E. WARREN AFB, WYOMING

Prepared for:

Air Force Center for Environmental Excellence
Brooks AFB, Texas

and

90th Support Group/DEVR
F.E. Warren AFB, Wyoming

by:

Engineering-Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado

August 1992

CONTENTS

TABLES

FIGURES

PART II

INTERIM TEST RESULTS

Initial bioventing pilot tests were completed at two sites on F. E. Warren Air Force Base (AFB), Wyoming during the period of 8 to 26 June 1992. The purpose of Part II is to describe the results of the initial pilot tests at these sites and to make specific recommendations for extended testing to determine the long-term impact of bioventing on site contaminants. Descriptions of the history, geology, and contamination at Spill Site 1 (BX Service Station) and Fire Training Area 1 are contained in Part I, the Test Work Plan.

1.0 SPILL SITE 1

1.1 Pilot Test Design

Installation of vent wells (VWs) and vapor monitoring points (MPs) began on 8 June 1992, and was completed on 9 June 1992. Drilling services were provided by the U.S. Geologic Survey (USGS) and well installation and soil sampling was directed by Mr. John Hall, the Engineering-Science, Inc. (ES) site manager. The following sections describe the final design and installation of the bioventing system on this site.

One VW, three MPs, and a blower unit were installed at Spill Site 1. The locations of the VW, MPs, and blower unit were changed slightly from those shown in the test work plan to avoid soil gas short circuiting through an abandoned 42-inch-diameter free product recovery well. Figures 1.1 and 1.2 depict the actual locations and vertical profiles respectively, of the VW and MPs completed at Spill Site 1. The background well for this site was existing groundwater monitoring well #57, located approximately 300 feet northwest of the site near the bank on Randall Avenue. Well #57 is constructed of 4-inch-diameter polyvinyl chloride (PVC) casing with approximately 3.5 feet of PVC screen extending above the water table.

Soils on this site were generally clayey and gravelly sand in the upper 6 to 7 feet with sandy clay from 7 feet to groundwater. Groundwater occurred at depths of 12.3 feet in the VW and 12.5 feet in the existing shallow monitoring wells.

1.1.1 Air-Injection Vent Well

The air-injection VW was installed following procedures described in the protocol document (Hinchee et al., 1992). Figure 1.3 shows construction details for the VW. The VW was installed in moderately contaminationed soil with the screened interval coinciding with the thin zone of contamination located in the sandy clay. The VW was constructed using 4-inch-diameter, Schedule 40 PVC

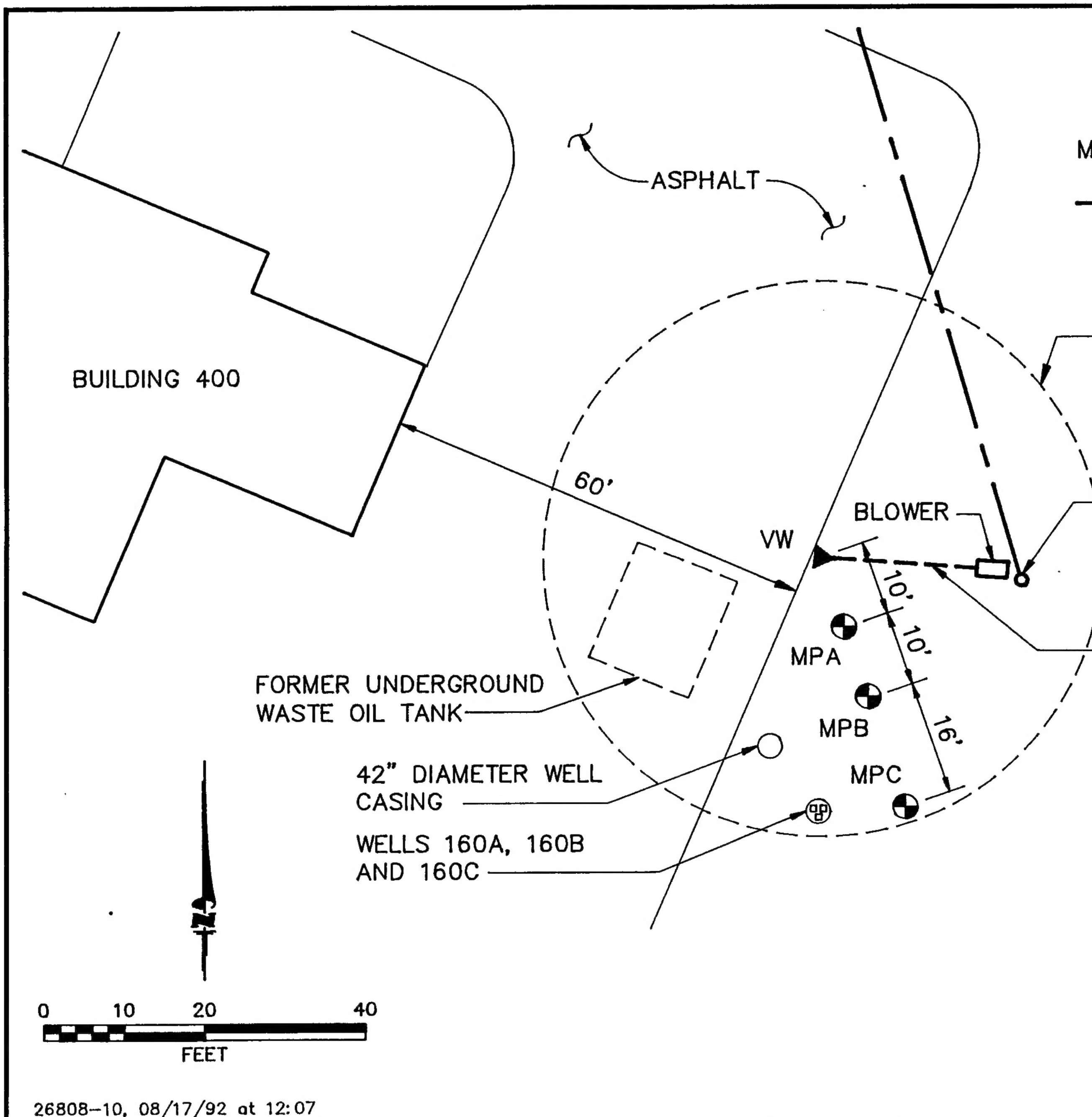

FIGURE 1.1

VENT WELL, MONITORING POINT, AND BLOWER LOCATIONS SPILL SITE 1

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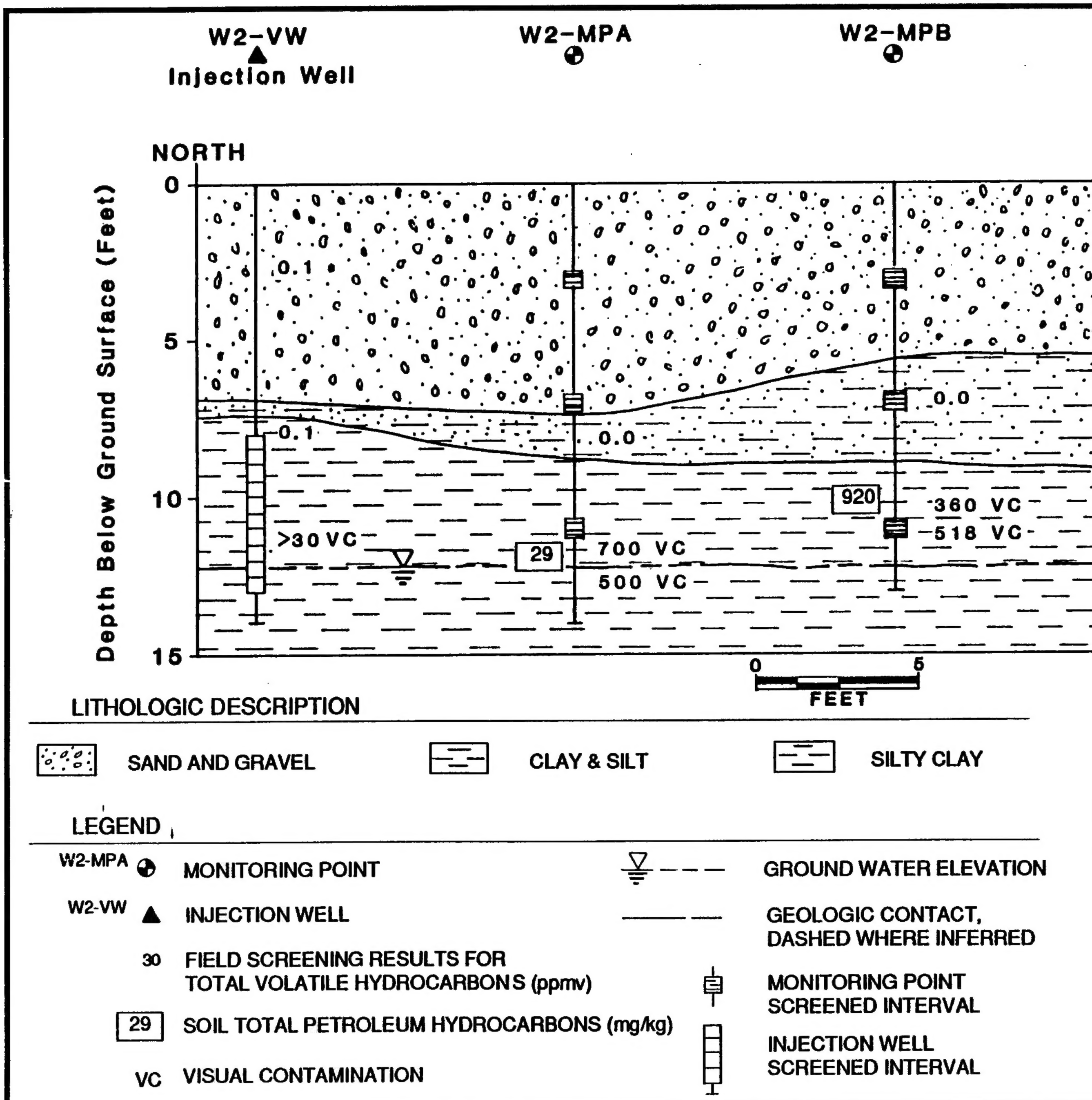

FIGURE 1.2

HYDROGEOLOGIC CROSS SECTION SPILL SITE 1

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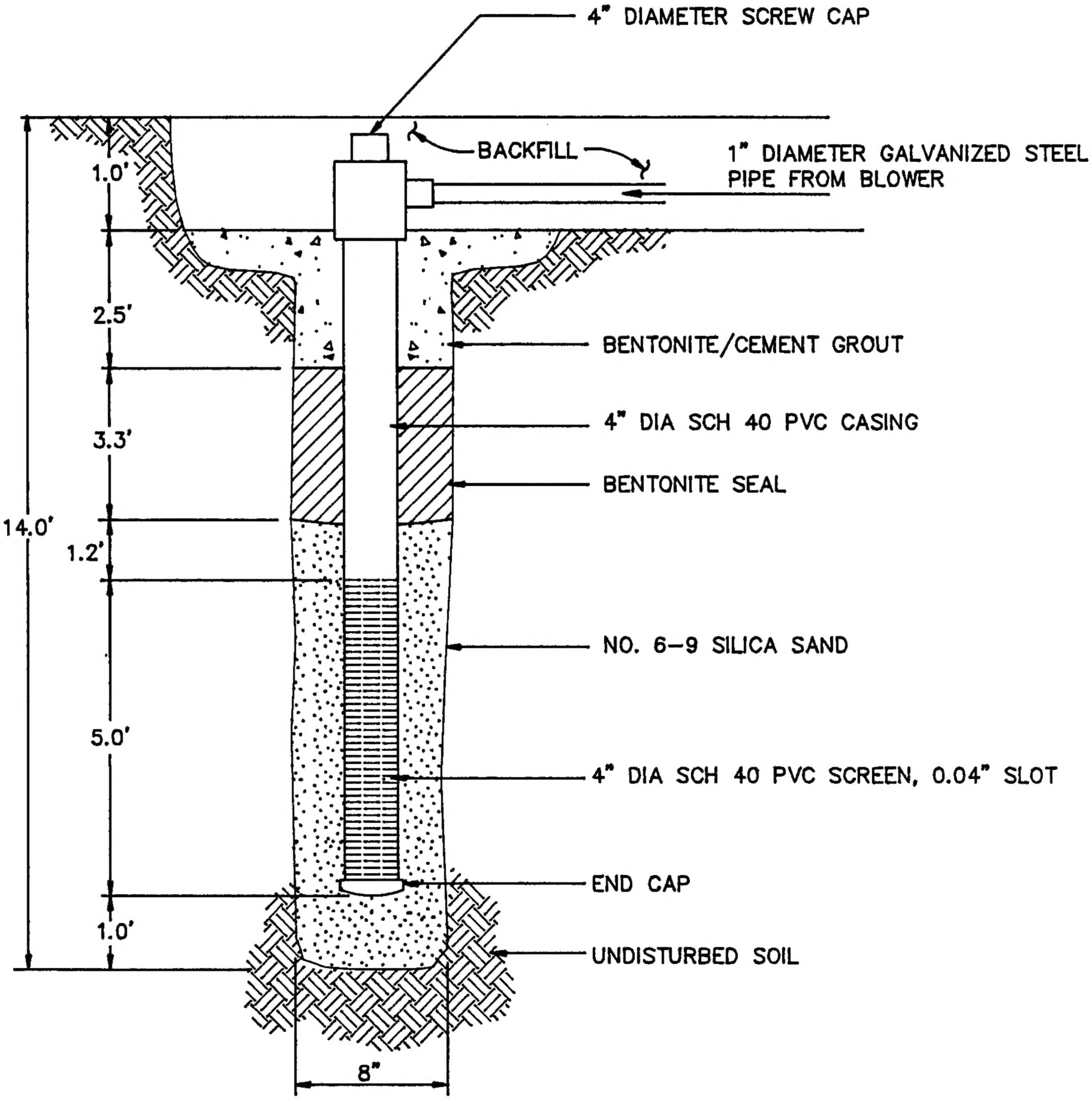

NOT TO SCALE

FIGURE 1.3

INJECTION VENT WELL CONSTRUCTION SPILL SITE 1

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casing with 5 feet of screen installed from 8 to 13 feet below ground surface. The annular space between the well casing and borehole was filled with 6-9 silica sand from the bottom of the borehole to approximately 1 foot above the well screen. Three feet of bentonite slurry was placed above the sand, followed by a cement-bentonite grout to within 18 inches of the surface. The top of the well was completed with a 4-inch-diameter tee with a screw cap to allow access to the well during the extended pilot test.

The configuration of the well and lithology at this site complicated efforts to obtain a good seal above the well screen. Because the screen is in the low-permeability sandy clay and most of the bentonite seal thickness is in the overlying sand and gravel, some short circuiting of air occurred around the bentonite seal during air injection. This was reduced by increasing the diameter of the grout collar around the VW.

1.1.2 Monitoring Points

The MP screens were installed at 3-, 7-, and 11-foot depths. The three MPs at this site were constructed as shown in Figures 1.2 and 1.4. Each screened interval point was constructed using a 6-inch section of 1-inch PVC well screen and a 1/4-inch PVC riser pipe extending to the surface. At the top of each riser, a ball valve and a 3/16-inch hose barb were installed . The top of each MP was completed with a flush-mounted metal well protector set in a concrete base. Thermocouples were installed at the 3- and 11-foot depths at MP A to measure soil temperature variations. Each MP was labeled as shown in Figure 1.2.

1.1.3 Blower Unit

A portable 3-horsepower Roots® URAI-22 positive-displacement blower unit was used at Spill Site 1 for the initial pilot test, and a similar fixed unit was installed for the extended pilot test. The fixed unit is energized by 230-volt, single-phase, 30-amp line power from a nearby power pole and breaker provided by the base. The extended-testing blower is currently injecting 30 standard cubic feet per minute (scfm) at 3,750 revolutions per minute (RPM) with a pressure rise of 5 pounds per square inch gauge (psig). The configuration, instrumentation, and specifications for this system are shown on Figure 1.5. Prior to departing the site, ES engineers provided an operations and maintenance briefing checklist and blower maintenance manual to base personnel. A copy of the checklist is provided in Appendix A.

1.2 Soil and Soil Gas Sampling Results

Hydrocarbon contamination at this site was generally confined to an interval from 9 to 13 feet below the surface. It appears that the source of this spill was a nearby former waste oil tank, and that the hydrocarbons have been distributed in a smear zone which corresponds with rising and falling groundwater elevations. Although MPs were completed at depths of 3, 7 and 11 feet at this site, only MP screens at 11 feet appeared to be in contaminated soil. The contaminated zone was identified based on visual appearance, odor, and volatile organic carbon (VOC) field screening results. Heavily contaminated soils were stained gray in color and

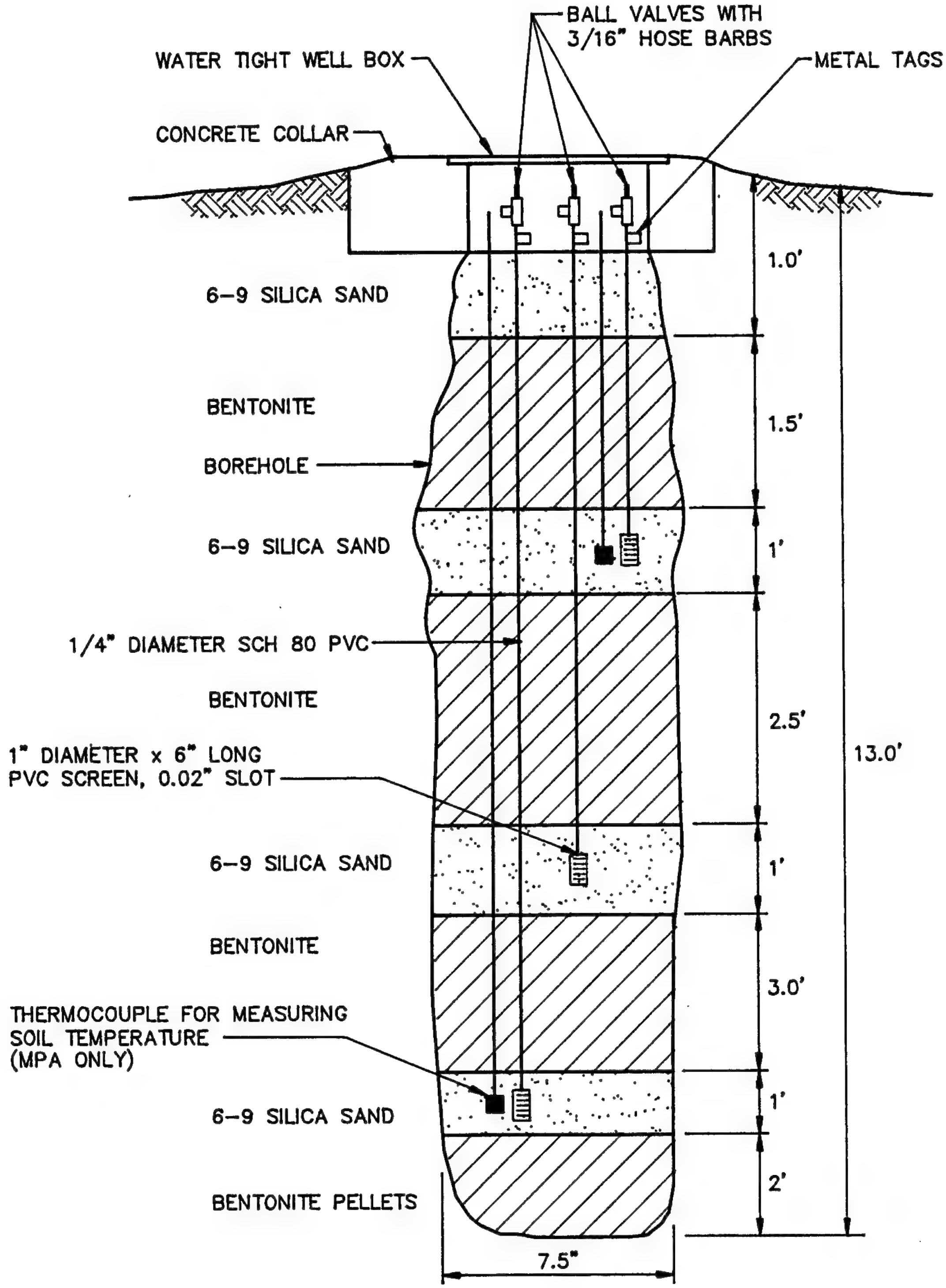

FIGURE 1.4

TYPICAL MONITORING POINT
CONSTRUCTION DETAIL
SPILL SITE 1

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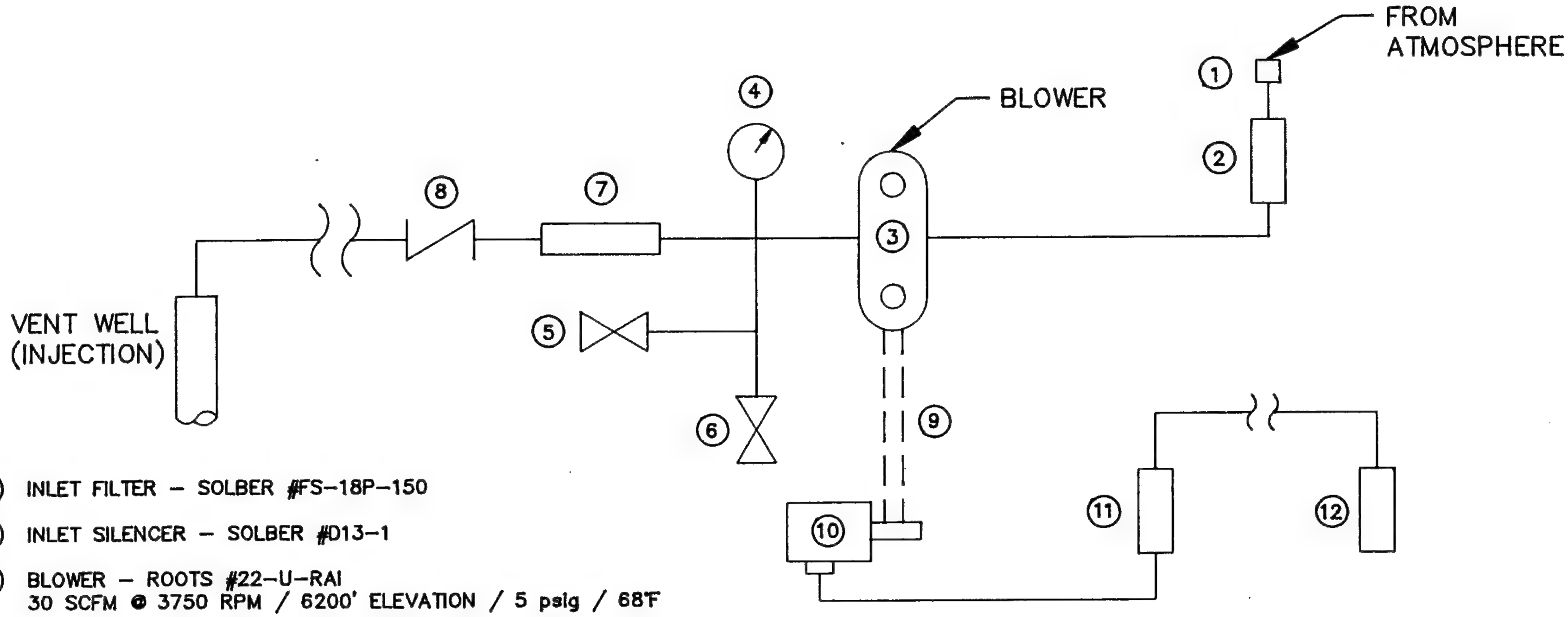

1. INLET FILTER – SOLBER #FS-18P-150
2. INLET SILENCER – SOLBER #D13-1
3. BLOWER – ROOTS #22-U-RAI
   30 SCFM @ 3750 RPM / 6200' ELEVATION / 5 psig / 68°F
4. PRESSURE GAGE (psig)
5. MANUAL PRESSURE RELIEF (BLEED) VALVE – 1" BALL
6. AUTOMATIC PRESSURE RELIEF VALVE – SET @ 6 psig
7. DISCHARGE SILENCER – SOLBER #D13-1
8. CHECK VALVE – 1"
9. BELT DRIVE
10. DRIVE MOTOR
    2 HP / 3450 RPM @ 60 Hz / 230 v / SINGLE PHASE / 15 A / FRAME SIZE 145T
11. STARTER
    230 v / 27 A / SINGLE PHASE / H1036 HEATER (10.8 A)
12. BREAKER BOX
    230 v / 50 A / SINGLE PHASE

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FIGURE 1.5

AS-BUILT BLOWER SYSTEM FOR AIR INJECTION

SPILL SITE 1/ FIRE TRAINING AREA 1

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Denver, Colorado

had a strong, diesel oil-like odor. Soil core samples were screened for VOCs using a Volatile Hydrocarbon Analyzer to determine the presence of contamination and to select soil samples for laboratory analysis. Soil samples for laboratory analysis were collected from MPA at a depth of 11 feet, from MPB at a depth of 10 feet, and from MPC at a depth of 11 feet. Procedures specified in the F. E. Warren AFB Sampling and Analysis Plan (USGS, 1991) were used for soil sampling. Soil gas samples were collected by extracting soil gas from the completed MP at 11 feet from MPA, MPB, and MPC. Soil samples were shipped via Federal Express® to the ES Berkeley laboratory for chemical and physical analysis. Soil gas samples were shipped via Federal Express® to Air Toxics, Inc. in Rancho Cordova, California for total volatile hydrocarbon (TVH) and benzene, toluene, ehtylbenzene, and xylenes (BTEX) analysis. The results of these analyses are provided in Table 1.1.

1.3 Exceptions To Test Protocol

Procedures described in the protocol document were used to complete treatability tests at both sites. Due to delays in providing power to the sites, the sequence of *in situ* respiration testing and soil gas permeability test had to be reversed. The only negative impact of this change was that the 0_2 measurement in all MPs could not be allowed to return to zero prior to starting the air permeability tests.

Air injection prior to *in situ* respiration testing was performed using two methods of air and helium injection. At Spill Site 1, helium was injected by metering a stream of pure helium into a 1-scfm air stream. This is the method prescribed in the protocol. An observed disadvantage of this method is a variation in injected helium concentrations due to changing MP back pressure and difficulties in keeping the helium flow constant with a rotometer. To improve the consistency of injected helium concentrations, an alternate method was attempted at the Fire Training Area site. At this site, air and helium were injected by metering in a premixed, 230-cubic foot cylinder of 99 percent air and 1 percent helium. The contents of this cylinder were injected over a 4-hour interval at a flow rate of approximately 1 scfm. The advantage of this method is a uniform helium concentration can be injected with minimum oversight. The disadvantage of this method is that more than 4 hours of injection may be required to reduce the diffusion effects around the MP. The cost and inconvenience of handling four to six large gas cylinders at each site may not be acceptable. ES will continue to refine and test these two helium-injection techniques and make a recommendation to AFCEE at a future date.

1.4 Test Results

1.4.1 Initial Soil Gas Chemistry

Prior to initiating any air injection at Spill Site 1, all MPs were purged for 10 minutes, and initial oxygen, carbon dioxide, and TVH concentrations were sampled using portable gas analyzers, as described in the protocol. Due to the relatively thin layer of contaminated silty soil at this site, the 10 minutes of initial purging may have caused oxygen a ted soil gas from upper soils to migrate into deeper. contaminated soils, giving false high oxygen readings. It appears that only one or two of the deep MPs at this site were oxygen depleted, and that upper sands

TABLE 1.1

SPILL SITE 1

SOIL AND SOIL GAS ANALYTICAL RESULTS

Analyte (Units)[a]	Sample Location-Depth (feet below ground surface)		
Soil Hydrocarbons	MPA-11	MPB-10	MPC-11
TPH (mg/kg)	29	920	250
Benzene (mg/kg)	ND[b]	ND	ND
Toluene (mg/kg)	ND	ND	ND
Ethyl benzene (mg/kg)	ND	4.9	8.2
Xylenes (mg/kg)	.13	34.0	51.0
Soil Gas Hydrocarbons	MPA-11	MPB-11	MPC-11
TVH (ppmv)	22	42000	4200
Benzene (ppmv)	.09	480	68
Toluene (ppmv)	.04	81	1.6
Ethyl benzene (ppmv)	.02	68	4.1
Xylenes (ppmv)	.08	320	19
Soil Inorganics	MPA-11	MPB-10	MPC-11
Iron (mg/kg)	9,990	12,800	10,800
Alkalinity (mg/kg as $CaCO_3$)	360	330	340
pH (units)	8.1	8.2	8.4
TKN (mg/kg)	65	48	53
Phosphates (mg/kg)	280	350	340
Soil Physical parameters	MPA-11	MPB-10	MPC-11
Moisture (% wt.)	19.5	22.4	20.5
Gravel (%)	0	0	0
Sand (%)	59	46	54
Silt (%)	20	32	27
Clay (%)	21	22	19

a/ mg/kg=milligrams per kilogram, ppmv=parts per million, volume per volume; $CaCO_3$=Calcium carbonate; TKN=total Kjeldahl nitrogen.
b/ ND=not detected.

TABLE 1.2

SPILL SITE 1

INITIAL SOIL GAS CHEMISTRY

MP	Depth (ft)	02 (%)	CO2(%)	TVH (ppmv)	TPH (mg/kg)
A	3	18.6	3.2	160	NS
B	3	19.3	1.6	142	NS
C	3	18.3	2.8	260	NS
A	7	16.0	3.6	180	NS
B	7	17.0	3.1	360	NS
C	7	17.5	2.8	260	NS
A	11	5.0	9.5	400	29
B	11	0.0	13.5	3600	920
C	11	0.0	12.5	1420	250
Background	8-11	20.9	0.7	NS	NS

NS=not sampled

contained sufficient oxygen to provide some diffusion Table 1.1 of oxygen into the contaminated silts and clays. Table 1.2 summarizes the initial soil gas chemistry at Spill Site 1. Total petroleum hydrocarbon (TPH) data are also provided to demonstrate the relationship between lower oxygen levels and more contaminated soils.

1.4.2 Soil Gas Permeability

A soil gas permeability test was conducted according to protocol procedures. Air was injected at a rate of approximately 24 scfm and an average pressure of approximately 8 psig. The pressure response at each MP is listed in Table 1.3. Due to the rapid response and relatively short time to achieve steady state conditions, the steady state method of determining soil gas permeability was selected. As discussed in the protocol, the dynamic method of determining soil gas permeability that is coded in the Hyperventilate® model is not appropriate for soils which reach steady state in less than 10 minutes. Using the steady-state method, a soil gas permeability value of 1.8 darcys was calculated for the deeper sandy-clay layer. A radius of pressure influence of at least 35 feet was observed in the upper sand layer and deeper sandy-clay layer.

1.4.3 Oxygen Influence

The depth and radius of oxygen increase in the subsurface resulting from air injection in the central VW is the primary design parameter for bioventing systems. Optimization of full-scale and multiple VW systems requires pilot testing to determine the volume of soil which can be oxygenated at a given flow rate and VW screen configuration.

Table 1.4 describes the change in soil gas oxygen levels that occurred during a 4-hour air injection test at the Spill Site 1 VW. This relatively brief air injection of 24 scfm produced a radius of oxygen influence of at least 35 feet in the upper sand layer. Significant oxygen increases were also measured at the 11 foot depth at radii of 10 and 20 feet from the VW. It is likely that high moisture levels MPC-11 (Table 1.1) prevented the withdrawal of a soil gas sample from the deep MP located 35 feet from the VW. This temporary blockage of the monitoring point screen may have resulted from the sampling pump pulling perched water into the sand pack. It is anticipated that the radius of oxygen influence for a long-term bioventing system on this site will exceed 35 feet at all depths. Future monitoring at this site will better define the treatment radius.

1.4.4 In Situ Respiration Rates

The results of *in situ* respiration testing at Spill Site 1 are presented in Figures 1.6 through 1.8. Oxygen loss from MPA occurred at a slow but steady rate. It is important to note that a soil sample taken from MPA-11 had a TPH concentration of only 29 mg/kg and an initial soil gas oxygen level of 8.5 percent, indicating that little biological activity is occurring near this MP. In contrast, oxygen utilization was rapid during the initial 600 minutes in MPB and MPC and then appeared to slow significantly. During the initial 600 minutes, helium diffusion at MPC-11 resulted

SPILL SITE 1

TABLE 1.3
PRESSURE RESPONSE
AIR PERMEABILITY TEST

Pressure Response In MP (inches of water)									
	MPA			MPB			MPC		
Depth (ft)	3	7	11	3	7	11	3	7	11
Elapsed Time (min)									
1	.40	.90	.60	.12	.22	.34	ND	ND	ND
2	.40	1.0	.90	ND	ND	ND	.10	.10	.14
3	.40	1.0	1.0	ND	ND	ND	ND	ND	ND
4	.45	1.05	1.05	.21	.27	.39	ND	ND	ND
6	.45	1.05	1.10	ND	ND	ND	.13	.13	.11
8	.47	1.05	1.10	ND	ND	ND	ND	ND	ND
10	.47	1.07	1.10	.16	.26	.36	.10	.10	.11
20	.48	1.09	1.13	.16	.25	.36	ND	ND	ND

ND = No Data

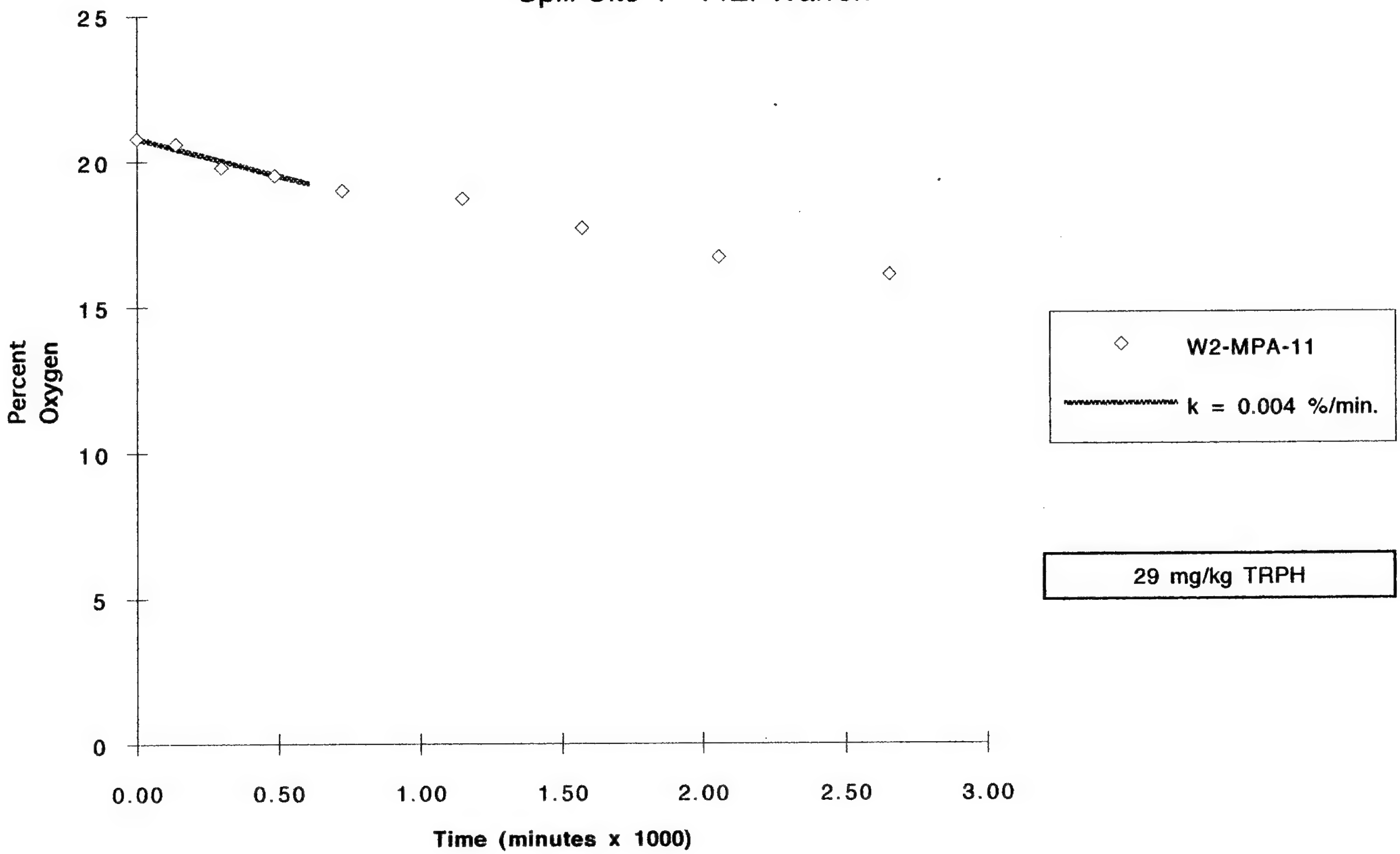
TABLE 1.4

SPILL SITE 1
INFLUENCE OF AIR INJECTION AT VENT WELL ON MONITORING POINT OXYGEN LEVELS

MP	Distance From VW (ft)	Depth(ft)	Initial O_2(%)	Final O_2(%)
A	10	3	18.6	20.7
B	20	3	19.3	20.5
C	35	3	18.3	19.0
A	10	7	16.0	20.6
B	20	7	17.0	18.8
C	35	7	17.5	18.8
A	10	11	8.5	20.5
B	20	11	0.0	16.9
C	35	11	0.0	NS

NS = Not sampled

Figure 1.6
Respiration Test
Spill Site 1 - F.E. Warren



Resp Test S.S. 1 - A

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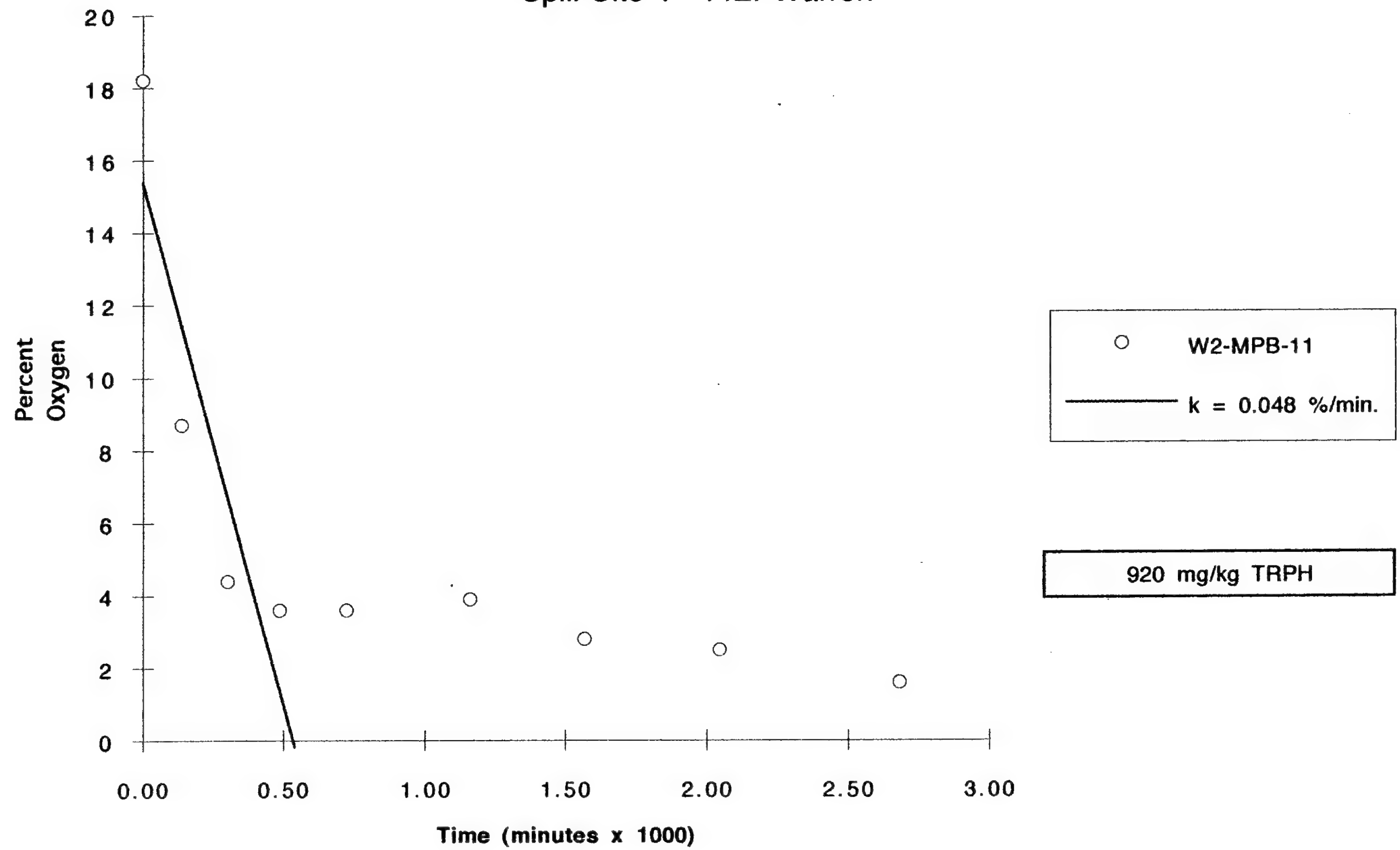
Figure 1.7
Respiration Test
Spill Site 1 - F.E. Warren



Resp Test S.S. 1 - B

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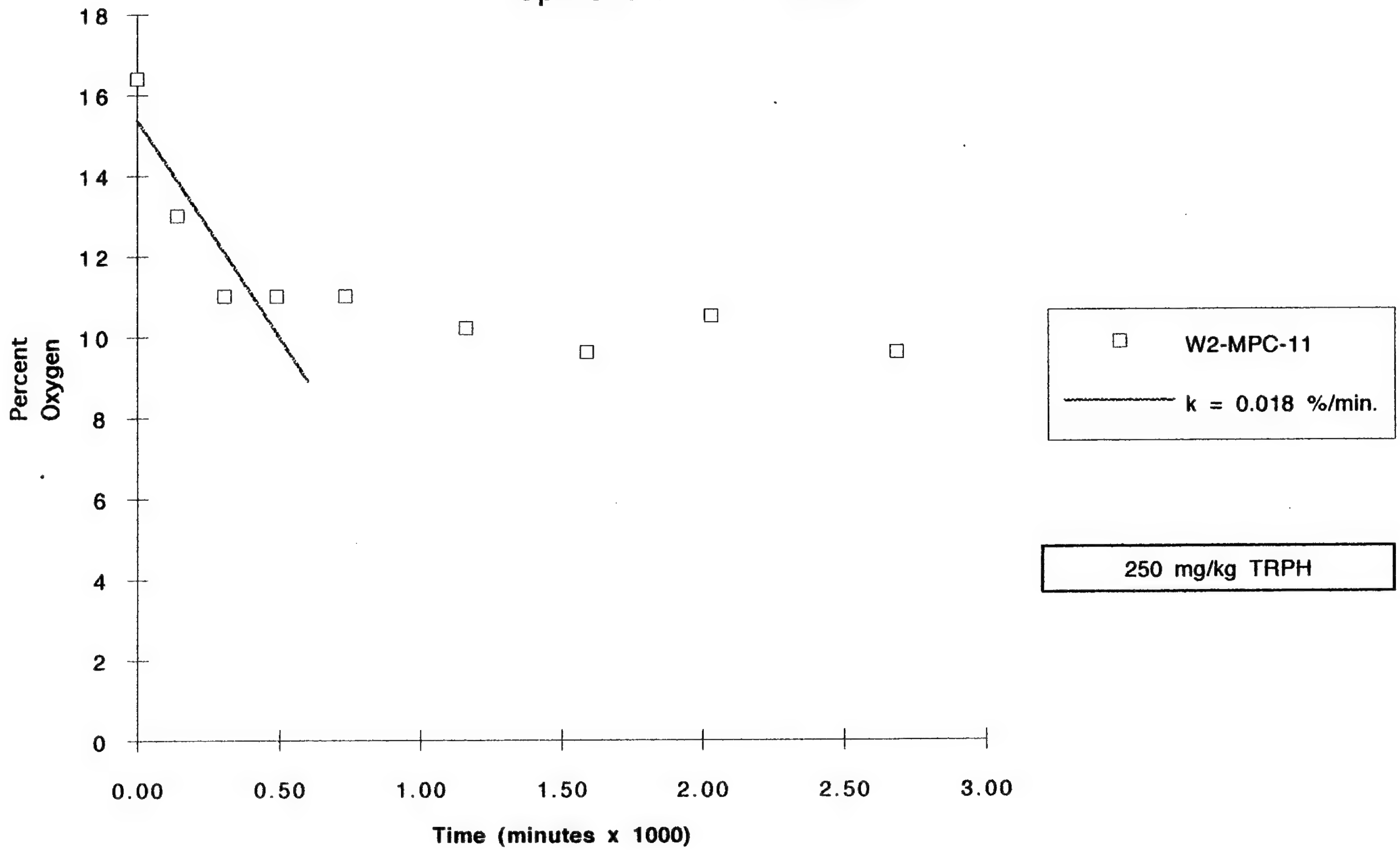
Figure 1.8
Respiration Test
Spill Site 1 - F.E. Warren



Resp Test S.S. 1 - C

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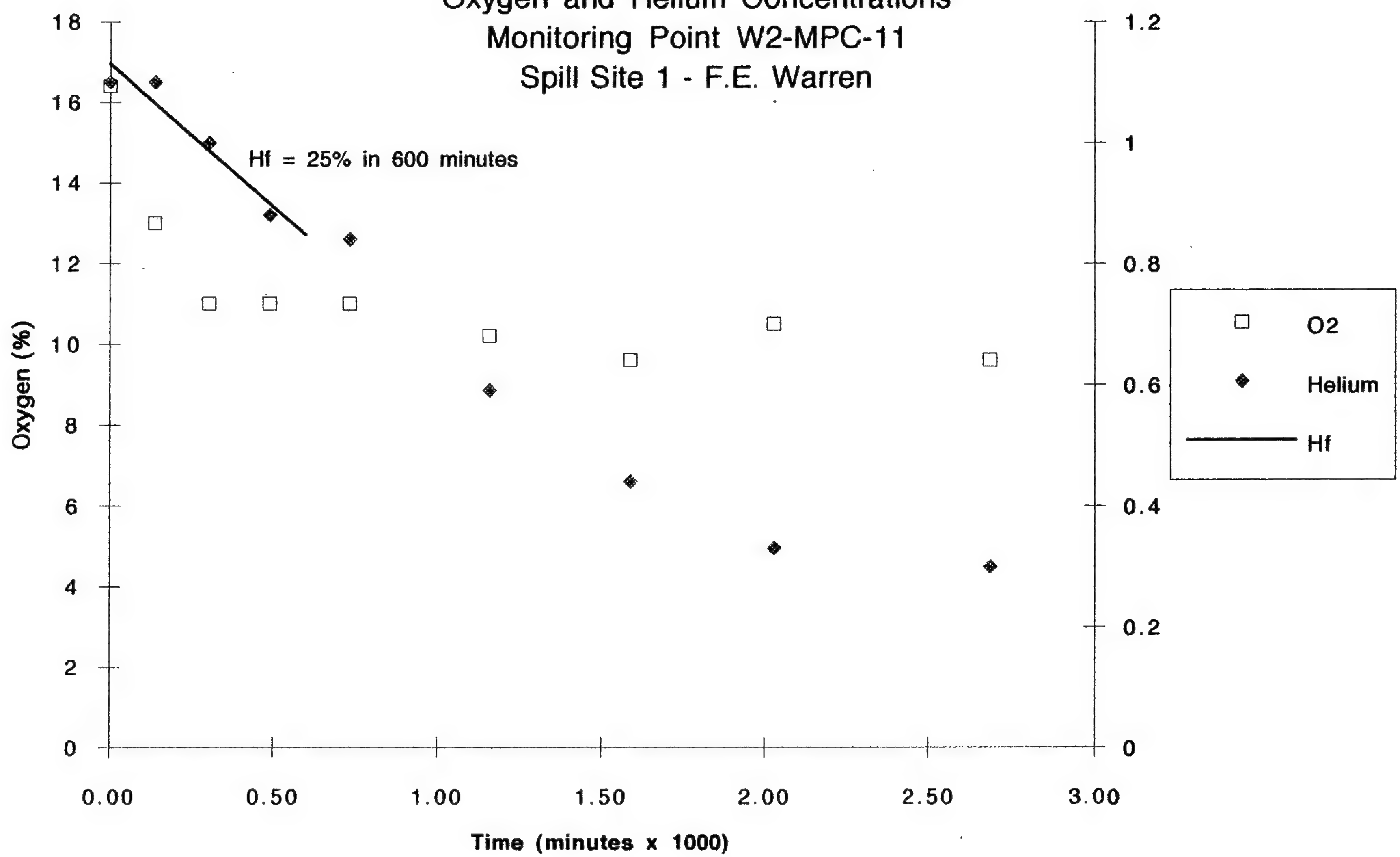
Figure 1.9
Respiration Test
Oxygen and Helium Concentrations
Monitoring Point W2-MPC-11
Spill Site 1 - F.E. Warren



O2/Helium Spill St. 1-FE Warren

8/19/92

in a fractional loss of approximately 25 percent of the initial helium concentration (Figure 1.9). Due to oxygen's greater molecular weight, helium will diffuse approximately three times faster than oxygen. This means that at MPC-11, approximately 8 percent of the initial oxygen may have been lost due to diffusion during the initial 600 minutes. Table 1.5 provides a summary of the observed and corrected oxygen utilization rates for Spill Site 1. As these MPs were all completed in the same soil formation, oxygen diffusion rates for MPA-11 and MPB-11 were assumed to be similar to the rate estimated for MPC-11. It is interesting to note that virtually all of the oxygen lost from MPA-11 was due to diffusion, based on the helium/oxygen diffusion estimate.

Based on the oxygen utilization rates observed at MPC-11 during the initial 600 minutes, an estimated 5 milligrams of fuel per kilogram of soil can be degraded each day on this site. This estimate is based on an average air-filled porosity of .06 liters per kilogram of soil and a conservative ratio of 3.5 milligrams of oxygen consumed for every 1 milligram of fuel degraded.

The apparent decrease in the oxygen utilization rate over time at this site has been observed by ES at other fuel spill sites where contamination levels and soil types are variable. Table 1.4 provides initial oxygen levels at nine MPs and clearly illustrates this variability. The protocol model for helium and oxygen diffusion assumes that each MP is surrounded by contaminated soil with zero oxygen and that the gradient of oxygen diffusion is always outward from the MP. It is apparent that at Spill Site 1, clean, oxygenated soil is in close proximity to a relatively thin layer of contaminated, zero-oxygen soil. In this situation , we believe that the oxygen diffusion gradient actually reverses over time. As oxygen is rapidly consumed by fuel-degrading bacteria, the inward diffusion of oxygen begins from clean soils. The effect of this inward diffusion is an apparent reduction in oxygen utilization rates over time. Because fuel biodegradation generally consumes oxygen at a rate that exceeds diffusion, soil gas eventually returns to zero in contaminated soil.

1.5 Recommendations

Initial bioventing tests at this Spill Site 1 indicate that oxygen has been depleted in the contaminated, deep sandy/clay soils, and that air injection is an effective method of increasing aerobic fuel biodegradation. The Air Force Center for Environmental Excellence (AFCEE) has recommended that air injection continue on this site to determine the long-term radius of oxygen influence and the effect of time, available nutrients, and changing temperatures on fuel biodegradation rates.

A small, positive-displacement blower has been installed at the site (Figure 1.5) to continue a low rate of air injection. In December 1992, ES will return to the site to sample and analyze the soil gas and conduct a repeat respiration test. To improve respiration test results, a longer period of air injection will be used to more evenly distribute oxygen and helium. In June 1993, a final respiration test will be conducted and soil and soil gas samples will be collected from the site to determine the degree of remediation achieved during the first year of treatment.

Based on the results of the first year of bioventing, AFCEE will recommend one of three options:

TABLE 1.5

SPILL SITE 1

APPARENT AND CORRECTED OXYGEN UTILIZATION RATES (0-600 MINUTES)

MP	Apparent O_2 loss (%/min)	Fractional Helium Loss (%)	Fractional Diffusion (%)	Estimated O_2 Diffusion (%/min)	Corrected O_2 Utilization (%/min)
W2-MPA-11	.004	25**	8**	.003	.001
W2-MPB-11	.048	25**	8**	.003	.045
W2-MPC-11	.018	25	8	.003	.015

** Based on helium diffusion from W2-MPC-11

Estimated Fuel Biodegradation Rates

1. Upgrade and continue operation of the bioventing system for full-scale remediation of the site. AFCEE can assist the base in obtaining regulatory approval for upgrading and continued operation. If additional removal of free product or groundwater treatment is required, AFCEE can assist in the design and construction of an integrated remediation system.
2. If final soil sampling indicates significant contaminant removal has occurred, AFCEE may recommend additional sampling to confirm that cleanup criteria have been achieved.
3. If significant difficulties or poor results are encountered during bioventing at this site, AFCEE could recommend the removal of the blower system and proper abandonment of the VW.

2.0 FIRE TRAINING AREA 1

2.1 Pilot Test Design

Installation of VW and vapor MPs began on 10 June 1992, and was completed on 11 June 1992. Drilling services were provided by the USGS and well installation and soil sampling was directed by Mr. John Hall, the ES site manager. The following sections describe the final design and installation of the bioventing system on this site an the results of the initial pilot testing.

One VW, three MPs, and one background MP were installed at Fire Training Area 1. The background well is located approximately 180 feet southwest of the VW. Figures 2.1 and 2.2 depict the locations and profiles of these wells. Soils on this site appeared to be largely fill material consisting of 4 to 7 feet of coarse sand, gravel and cinders overlying clay, silt, and fine sand. Groundwater was encountered between 7 and 8 feet below ground surface.

2.1.1 Air-Injection Vent Well

The air injection VW was installed following procedures described in the protocol document (Hinchee et al., 1992. Figure 2.3 shows construction details for the VW. The locations of the VW and MPs are the same as described in the work plan, but the depths are shallower because groundwater was encounter at only 7 feet.

The VW was installed with the screened interval coinciding with the zone of highest contamination, with the lower part of the screen in the silty clay and the upper part in sand and gravel (Figure 2.2). The VW was constructed using 4-inch-diameter, Schedule 40 PVC casing with 5 feet of screen installed from 3 to 8 feet below ground surface. The annular space between the well casing and borehole was filled with 6-9 silica sand from the bottom of the borehole to approximately 6 inches above the well screen, followed by 2 feet of bentonite slurry. Concrete was then used to fill the remaining annular space and to form a pad around the well casing. Short circuiting was not observed around the top of this well. The top of the VW was completed with a 4-inch-diameter tee with a screw cap to allow access to the well during the extended pilot test.

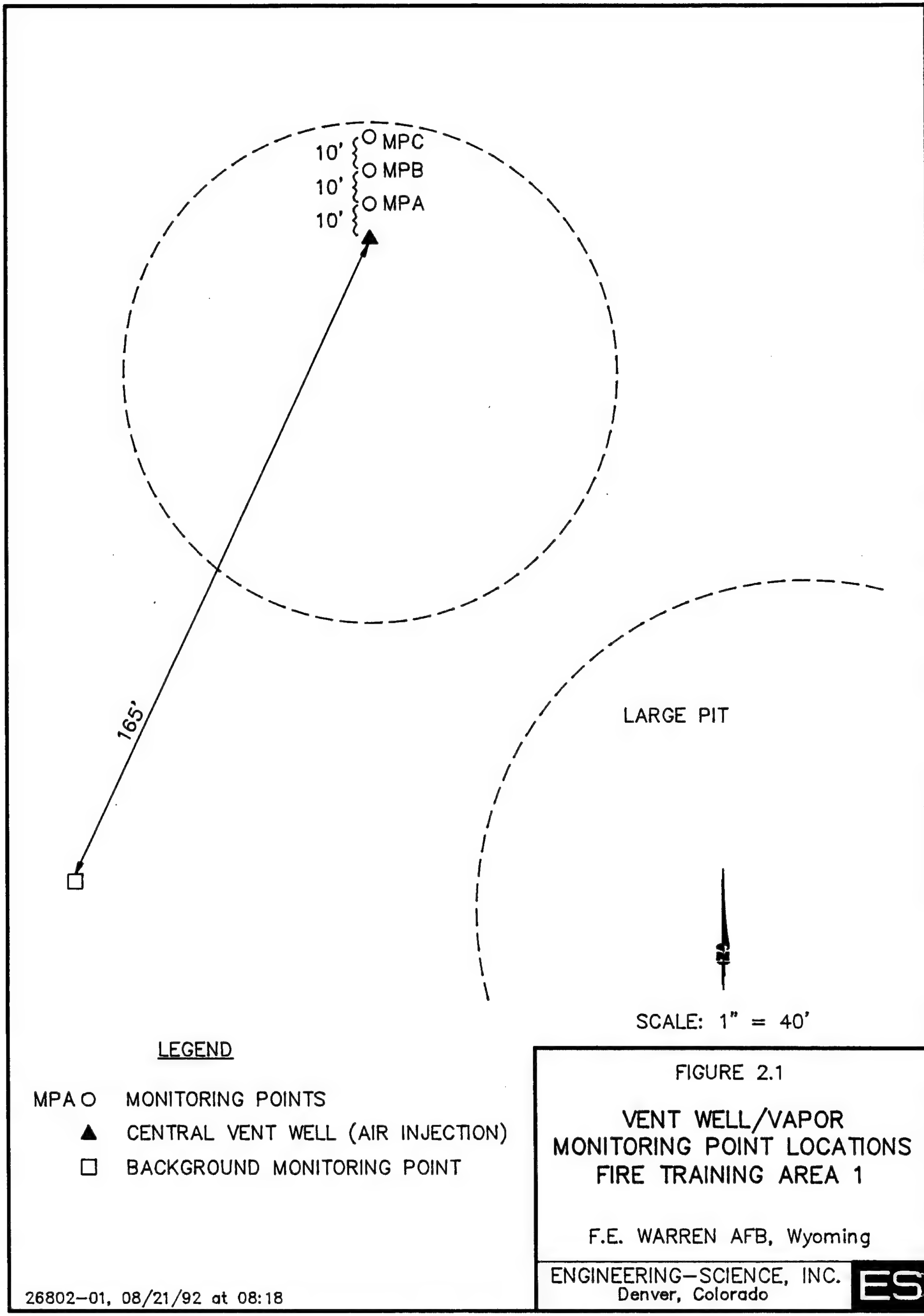


FIGURE 2.1

VENT WELL/VAPOR MONITORING POINT LOCATIONS FIRE TRAINING AREA 1

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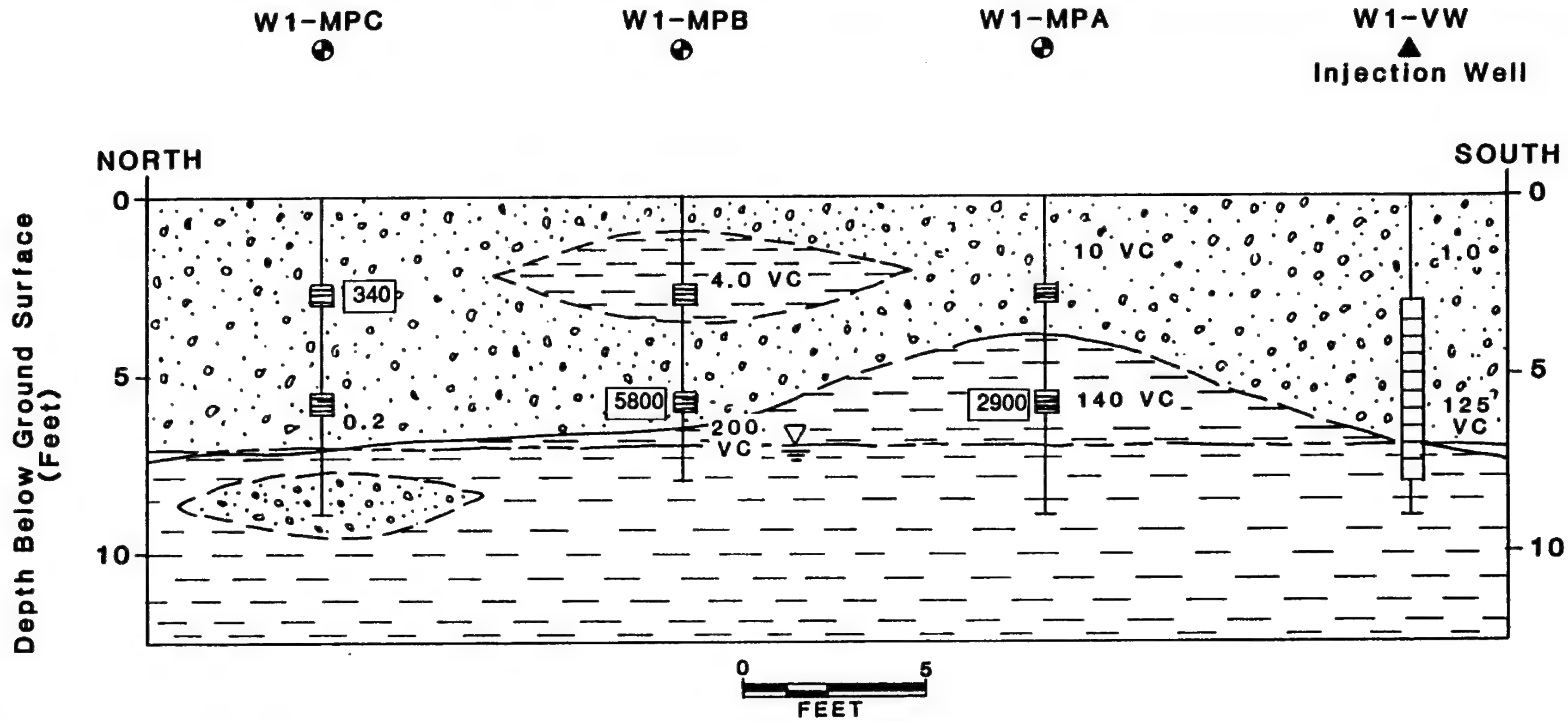

LITHOLOGIC DESCRIPTION

SAND AND GRAVEL

CLAY & SILT

LEGEND

W1-MPA MONITORING POINT

W1-VW INJECTION WELL

200 FIELD SCREENING RESULTS FOR TOTAL VOLATILE HYDROCARBONS (ppmv)

340 SOIL TOTAL PETROLEUM HYDROCARBONS (mg/kg)

VC VISUAL CONTAMINATION

GROUND WATER ELEVATION

GEOLOGIC CONTACT, DASHED WHERE INFERRED

MONITORING POINT SCREENED INTERVAL

INJECTION WELL SCREENED INTERVAL

FIGURE 2.2

HYDROGEOLOGIC CROSS SECTION FIRE TRAINING AREA

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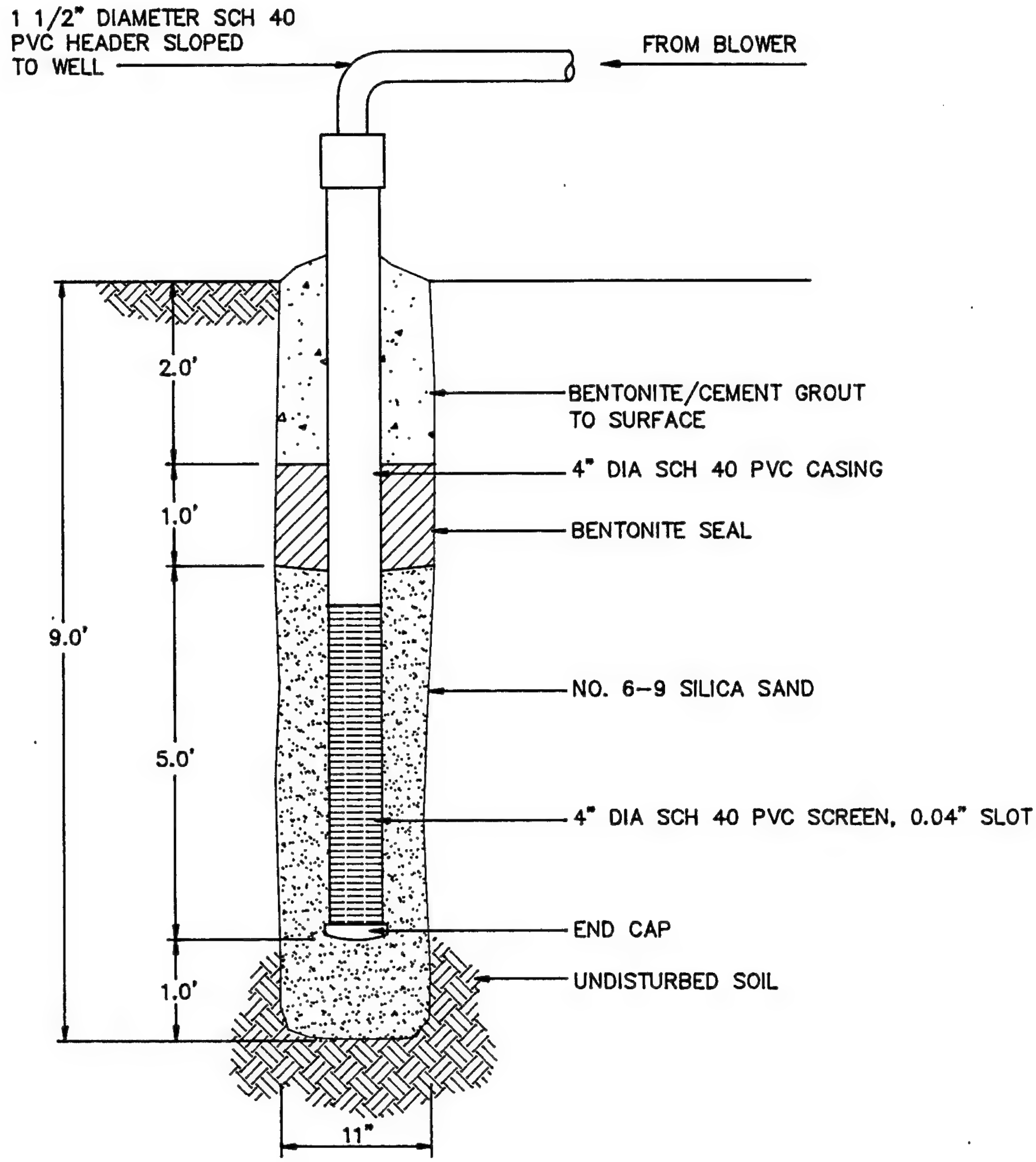
ENGINEERING-SCIENCE, INC.
Denver, Colorado

ES



NOT TO SCALE

FIGURE 2.3

INJECTION VENTING WELL CONSTRUCTION FIRE TRAINING AREA 1

F.E. WARREN AFB, WYOMING

ENGINEERING-SCIENCE, INC.
Denver, Colorado

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2.1.2 Monitoring Points

The MP screens were installed at depths of 3 and 6 feet. All three MPs and the background MP were constructed as shown in Figure 2.4. Each screened interval point consisted of a 6-inch section of 1-inch PVC well screen and ¼-inch PVC riser pipe extending to the surface. At the top of each riser a ball valve and a 3/16-inch hose barb were installed for soil gas sampling. The top of each MP was completed with a flush-mounted well protector set in a concrete base. At MPA, thermocouples were installed at the 3- and 6-foot depths to measure soil temperature variations. Each MP was labeled as shown on Figure 2.1.

2.1.3 Blower Unit

A portable 3-horsepower Roots® URAI-22 positive-displacement blower unit was used at the Fire Training Area 1 site for initial pilot testing. The unit was energized by 230-volt, single-phase, 30-Amp line power from a nearby power pole and breaker provided by the base. The configuration, instrumentation, and specifications for this system are shown on Figure 1.5. Because this site is a candidate for a full-scale Air Force Civil Engineering Service Agency (AFCESA) bioventing demonstration, a small, fixed blower was not installed at this site for extended testing.

2.2 Soil and Soil Gas Sampling Results

Based on visual appearance and VOC screening, hydrocarbon contamination in soil at this site extended from approximately 2 feet below ground surface to the water table. The level of contamination appeared to increase with depth, with the highest levels occurring within a few feet above the water table. Heavily contaminated soils were stained gray or black and had a diesel oil-like odor. Soil core samples were screened for VOCs using a Trace-Techtor® hydrocarbon analyzer to determine the presence of contamination and to select soil samples for laboratory analysis. Soil samples were collected from MPA at a depth of 6 feet, from MPB at a depth of 7 feet, and from MPC at a depth of 3 feet. MPs were completed at depths of 3 and 6 feet at this site, however, only the MPs screened at 6 feet were in significantly contaminated soil.

Soil gas samples were collected by extracting soil gas from a depth of 6 feet in MPA, MPB, and MPC. Soil samples were shipped via Federal Express® to the ES Berkeley Laboratory for chemical and physical analysis. Soil gas samples were shipped via Federal Express® to Air Toxics, Inc. in Rancho Cordova, California for and BTEX analysis. The results of these analyses are presented in Table 2.1.

2.3 Exceptions To Test Protocol

The exceptions described in Section 1.3 pertain to the Fire Training Area 1 pilot test as well.

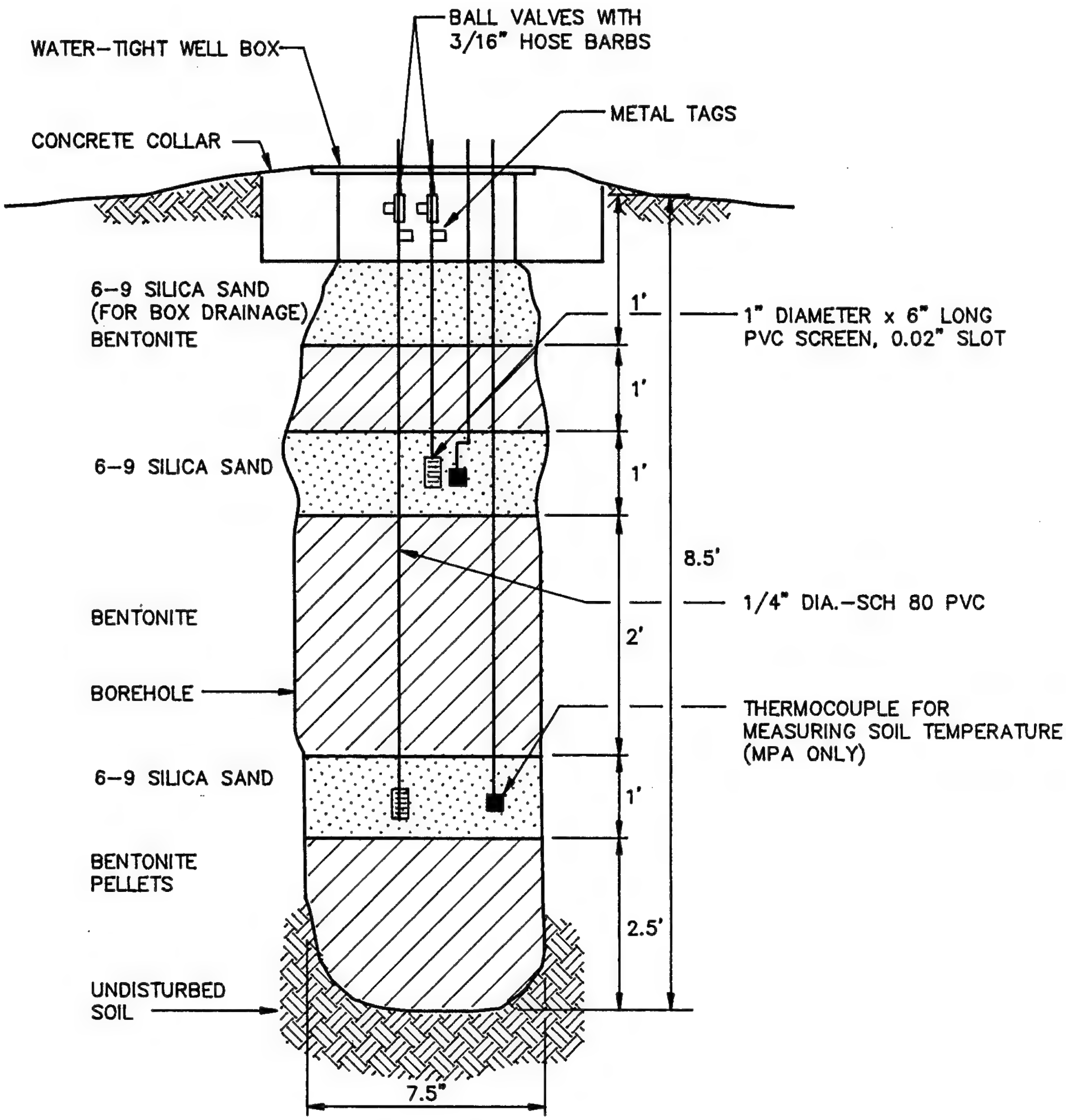

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FIGURE 2.4

TYPICAL MONITORING POINT
CONSTRUCTION DETAIL
FIRE TRAINING AREA 1

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ENGINEERING-SCIENCE, INC.
Denver, Colorado

ES

TABLE 2.1

FIRE TRAINING AREA 1

SOIL AND SOIL GAS ANALYTICAL RESULTS

Analyte (Units)[a]	**Sample Location-Depth (feet below ground surface)**		
	MPA-6	MPB-7	MPC-3
Soil Hydrocarbons			
TPH (mg/kg)	2900	5800	340
Benzene (mg/kg)	ND[b]	ND	ND
Toluene (mg/kg)	.71	ND	ND
Ethyl Benzene (mg/kg)	.53	ND	ND
Xylenes (mg/kg)	.70	.96	ND
Soil Gas Hydrocarbons	MPA-6	MPB-6	MPC-6
TVH (ppmv)	2900	270	8.4
Benzene (ppmv)	2.1	.64	ND
Toluene (ppmv)	6.8	.73	ND
Ethyl Benzene (ppmv)	5.3	.40	ND
Xylenes (ppmv)	14	1.2	ND
Soil Inorganics	MPA-6	MPB-7	MPC-3
Iron (mg/kg)	8350	13200	39000
Alkalinity (mg/kg as $CaCO_3$)	1600	870	1300
pH (units)	8.3	8.0	7.2
TKN (mg/kg)	300	280	3300
Phosphates (mg/kg)	320	660	330
Soil Physical parameters	MPA-6	MPB-7	MPC-3
Moisture (% wt.)	15.7	21.7	24.6
Gravel (%)	0	0	11
Sand (%)	53	55	63
Silt (%)	32	31	21
Clay (%)	15	14	5
Temperature (°C)			16.1

[a] mg/kg = milligrams per kilogram; ppmv = parts per million, volume per volume; $CaCO_3$ = calcium carbonate; TKN = total Kjeldahl nitrogen.
[b] ND = not detected.

2.4 Test Results

2.4.1 Initial Soil Gas Chemistry

Prior to initiating any air injection at the Fire Training Area, all MPs were purged for 10 minutes and initial oxygen, carbon dioxide and TVH concentrations were sampled using portable gas analyzers as described in the protocol. Due to the relatively thin layer of contaminated soil on this site, the 10 minutes of initial purging appears to have caused oxygenated soil gas from upper soils to migrate into deeper contaminated soils giving false high oxygen readings. Several days later, and prior to initiating any air injection on the site, the soil gas was resampled using only a 1 minute purge. Table 2.2 summarizes the soil gas chemistry at the Fire Training Area 1 site based on the 1 minute purge. Only two of the deep MPs at this site, MPA-6 and MPC-6, could be considered oxygen depleted. The upper sand appears to contain sufficient oxygen to provide some diffusion of oxygen into the lower contaminated silts and clays.

2.4.2 Soil Gas Permeability

A soil gas permeability test was conducted according to Protocol procedures. Air was injected at a rate of approximately 42 scfm and a pressure of 1.5 psig. The pressure response at each MP is recorded in Table 2.3. Due to the rapid response and relatively short time to achieve steady-state conditions, the steady-state method of determining soil gas permeability was selected. As discussed in the Protocol, the dynamic method of determining soil gas permeability that is coded in the Hyperventilate® model is not appropriate for soils which reach steady state in less than 10 minutes. Using the steady-state method, soil gas permeability in the upper sand was estimated at 17 darcys, typical for sandy soils. A radius of pressure influence of between 20 and 30 feet was observed at both 3- and 6-foot depths in the upper sand layer.

2.4.3 Oxygen Influence

The depth and radius of oxygen increase in the subsurface resulting from air injection in the central VW is the primary design parameter for bioventing systems. Optimization of full-scale and multiple VW systems requires pilot testing to determine the volume of soil which can be oxygenated at a given flow rate and VW screen configuration.

Table 2.4 describes the change in soil gas oxygen levels that occurred during a 1 hour and 52 minute period of air injection at this site. This relatively brief period of air injection at a rate of 42 scfm produced a radius of oxygen influence of between 20 and 30 feet at both 3- and 6-foot depths in the upper sand layer. It is anticipated that the radius of oxygen influence for a long-term bioventing system at this site will exceed 30 feet at all depths.

2.4.4 In Situ Respiration Rates

The results of *in situ* respiration testing at Fire Training Area 1 are presented in Figures 2.5 through 2.8. Oxygen loss from MPA-6 occurred at the fastest rate. This MP also had the lowest initial oxygen concentration. MPB-7 and MPC-6 exhibited

TABLE 2.2
FIRE TRAINING AREA 1
INITIAL SOIL GAS CHEMISTRY

MP	Depth (ft)	02 (%)	CO2 (%)	TVH (ppmv)	TPH (mg/kg)
A	3	15.0	5.0	180	NS
B	3	10.0	9.1	240	NS
C	3	7.1	12.0	260	340
A	6	0.2	12.5	1740	2900
B	7	6.0	11.5	340	5800
C	6	2.5	16.0	240	NS

NS = not sampled

TABLE 2.3
FIRE TRAINING AREA 1
PRESSURE RESPONSE
AIR PERMEABILITY TEST

Pressure Response In MP (inches H2O)

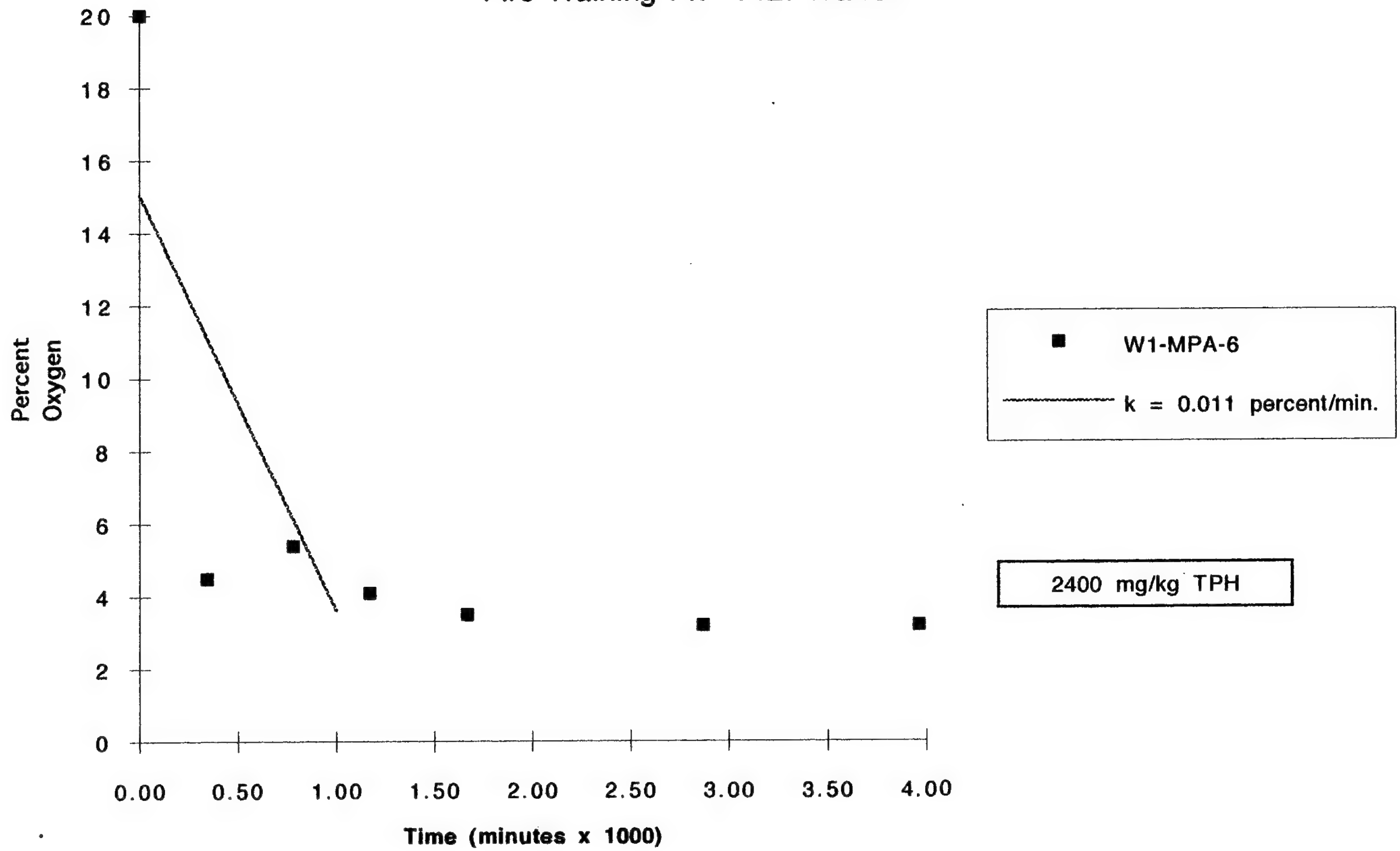
	MPA		MPB		MPC	
Depth (ft)	3	6	3	6	3	6
Elapsed Time (min)						
1	0.25	0.24	0.20	0.20	0.03	0.03
2	0.26	0.24	0.19	0.20	0.03	0.03
3	0.25	0.24	0.20	0.20	0.03	0.03
4	0.24	0.22	0.19	0.20	0.02	0.03
5	0.23	0.22	0.20	0.20	0.04	0.04

TABLE 2.4

FIRE TRAINING AREA 1
INFLUENCE OF AIR INJECTION AT VENT WELL ON MONITORING POINT OXYGEN LEVELS

MP	Distance From VW (ft)	Depth (ft)	Initial O2 (%)	Final O2 (%)
A	10	3	15.0	20.8
B	20	3	10.0	14.0
C	30	3	7.1	7.5
A	10	6	0.2	4.5
B	20	6	6.0	16.0
C	30	6	2.5	3.6

Figure 2.5
Respiration Test
Fire Training Pit - F.E. Warren



Resp Test FTP - A

8/19/92

Figure 2.6
Respiration Test
Fire Training Pit - F.E. Warren

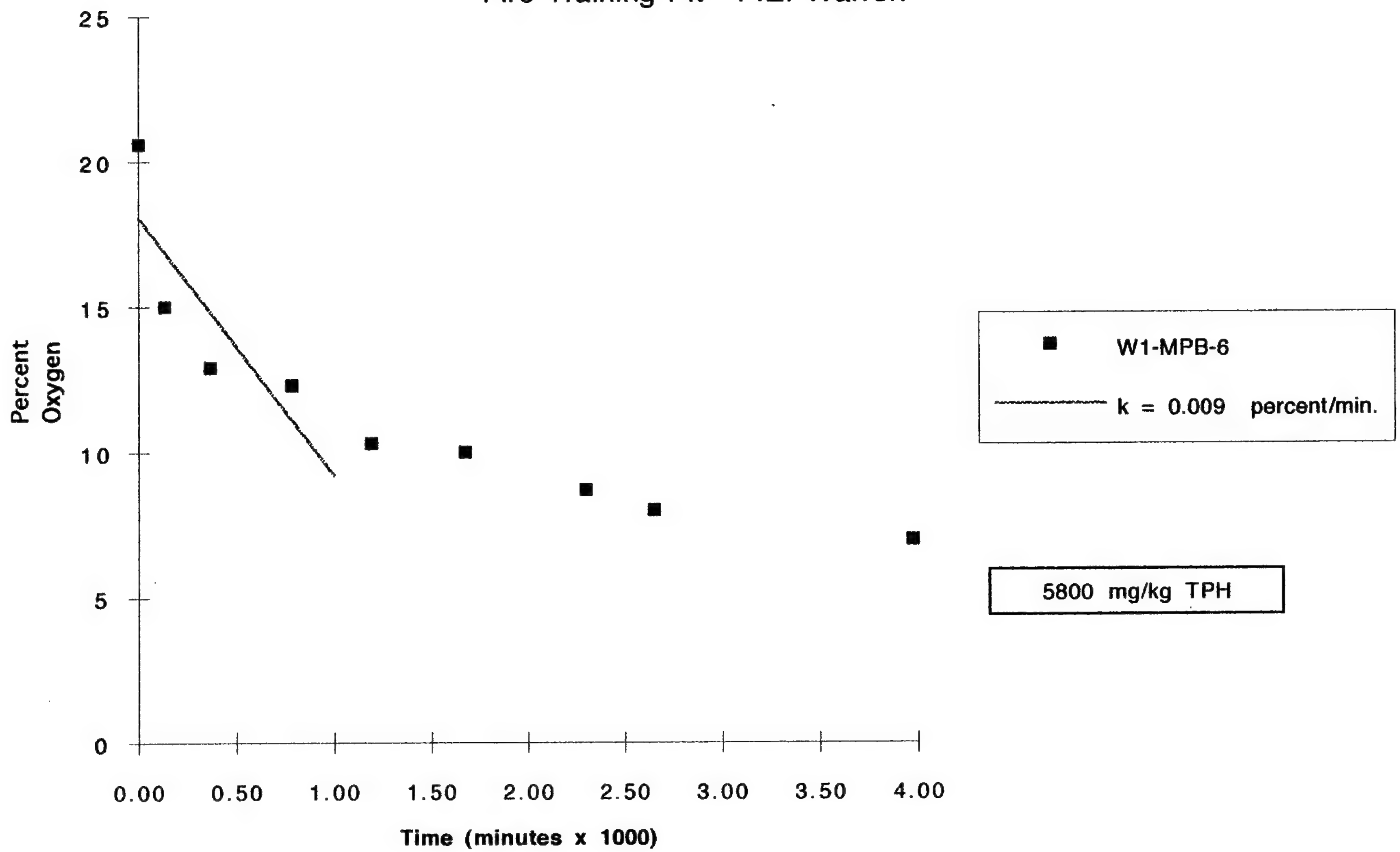
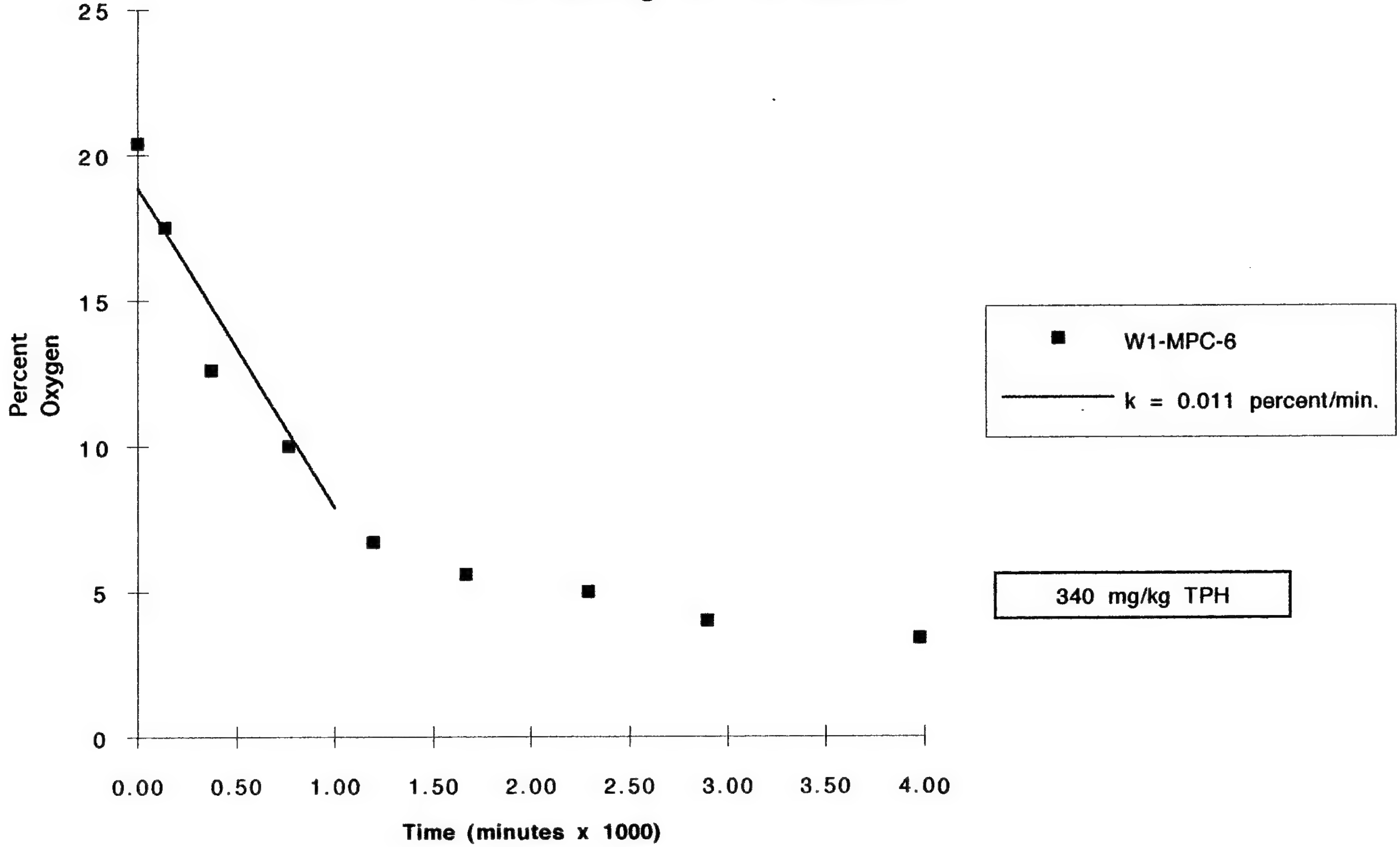


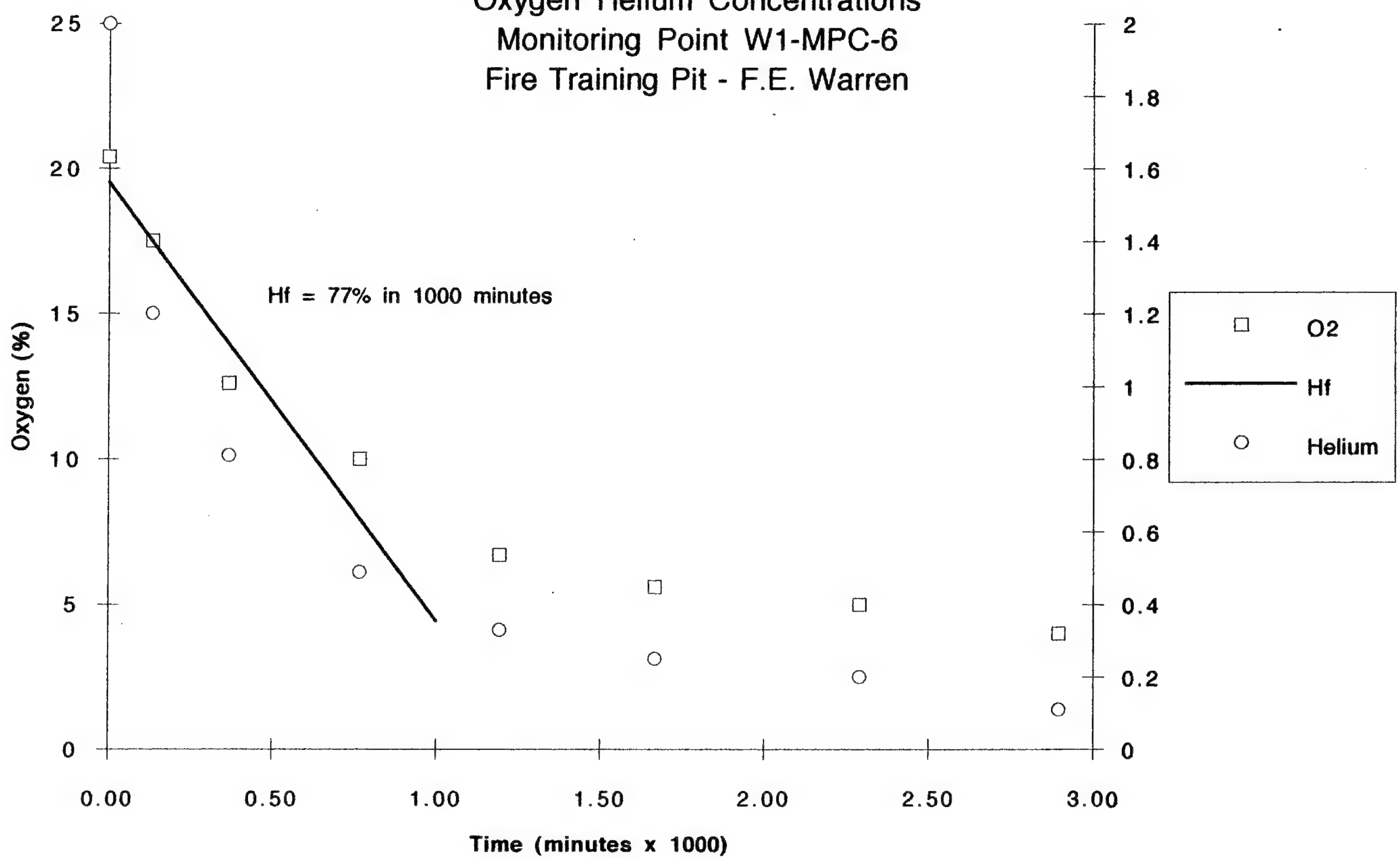
Figure 2.7
Respiration Test
Fire Training Pit - F.E. Warren



Resp Test FTP - C

8/19/92

Figure 2.8
Respiration Test
Oxygen Helium Concentrations
Monitoring Point W1-MPC-6
Fire Training Pit - F.E. Warren



O2/Helium FTP - FE Warren

8/19/92

similar oxygen losses during the first 1,000 minutes of the test, however, the rate of oxygen loss slowed more rapidly in MPB-7. It is possible that MPB-7 is located on the boundary of an oxygen-rich zone, it had an initial oxygen level of 6.0 percent yet had a TPH value of 5,800 mg/kg. A leak in the MP valve could also have occurred. This MP will be carefully checked and leak tested prior to the next respiration test. During the initial 1000 minutes, helium diffusion at MPC-6 resulted in a fractional loss of approximately 77 percent of the initial helium concentration (Figure 2.7). Due to oxygen's greater molecular weight, helium will diffuse approximately three times faster than oxygen. This means that at MPC-11, approximately 26 percent of the initial oxygen may have been lost due to diffusion during the initial 1,000 minutes. Table 2.5 provides a summary of the observed and corrected oxygen utilization rates for the Fire Training Area 1. Due to similarity in surrounding soils, the oxygen diffusion rate for MPB-6 and MPA-6 were assumed to be similar to the rate estimated for MPC-6.

Based on the oxygen utilization rates observed at MPC-6 during the initial 1,000 minutes of the test, an estimated 1.6 milligrams of fuel per kilogram of soil can be degraded each day on this site. This estimate is based on an average air-filled porosity of 0.05 liters per kilogram of soil and a conservative ratio of 3.5 milligrams of oxygen consumed for every 1 milligram of fuel degraded.

The apparent decrease in oxygen utilization over time at this site has been observed by ES at other fuel spill sites where contamination levels and soil types are variable. Table 2.3 provides initial oxygen levels at six MPs and clearly illustrates this variability. The protocol model for helium and oxygen diffusion assumes that each MP is surrounded by contaminated soil with zero oxygen, and that the gradient of oxygen diffusion is always outward from the monitoring point. It is apparent that at this site, clean, oxygenated soil is in close proximity to pockets of contaminated, zero oxygen soil. In this situation, we believe that the oxygen diffusion gradient actually reverses over time. As oxygen is rapidly consumed by fuel-degrading bacteria, the inward diffusion of oxygen begins from clean soils. The effect of this inward diffusion is an apparent reduction in oxygen utilization rates over time. Because fuel biodegradation generally consumes oxygen at a rate that exceeds diffusion, soil gas eventually returns to zero in contaminated soil.

2.5 Recommendations

Initial bioventing tests of Fire Training Area 1 indicate that oxygen has been depleted in the contaminated, deep soils and that air injection is an effective method of increasing aerobic fuel biodegradation. The AFCESA is considering this site for a full-scale bioventing demonstration. The following recommendations should be considered for a full-scale bioventing design:

1. Horizontal air-injection lines may be more efficient than a vertical VW for supplying oxygen to deeper oxygen-depleted soils. Because the upper 5 feet of these sandy soils contain sufficient oxygen to sustain biodegradation, air flow focused through the 5- to 7-foot depth interval will more efficiently deliver oxygen to the contaminated soil horizon.

TABLE 2.5

FIRE TRAINING AREA 1

OBSERVED AND CORRECTED OXYGEN UTILIZATION RATES

	Apparent O_2 loss (k) (%/min)	Fractional Helium Loss (%)	Fractional Diffusion (%)	Estimated O_2 Diffusion (%/min)	Corrected O_2 Utilization (%/min)
W1-MPA-6	.011	77*	26*	.005*	.006*
W1-MPB-7	.009	77*	26*	.005*	.004*
W1-MPC-6	.011	77	26	.005	.006

* Based on helium diffusion from W1-MPC-6

A7-3-11

2. Soil gas probes may provide a better oxygen profile in these soils. ES had difficulty driving soil gas probes beyond a 2 foot depth. The major advantage of soil gas probes would be a reduction in soil gas purging time and more accurate respiration tests with the elimination of over purging.

3. As expected, relatively high moisture levels exist in the 5- to 7-foot depth interval. The estimated air-filled porosity of this interval was only 0.05 liters per kilogram of soil. Bioventing efffectiveness in this capillary fringe would be improved if coupled with a dewatering system which lowers the water table 1 or 2 feet and increases the air-filled porosity of deeper soils.

REFERENCES

U.S.G.S., 1991. General Sampling and Analysis Plan, Volume I: Field Sampling Plan for Remedial Investigation Feasibility Study at F.E. Warren Air Force Base, Wyoming: Prepared by the U.S. Geological Survey.

Hinchee, R.E., R.N. Miller, D.C. Downey. Test Plan and Technical Protocol for a Field Treatability Test for Bioventing. Prepared for USAF Center for Environmental Excellence. May 1992.

APPENDIX A

O & M CHECKLIST

BLOWER MAINTENANCE SCHEDULE

SPILL SITE 1

F. E. WARREN AFB, WYOMING

DAILY MAINTENANCE

Check to see if blower is running. Drive by and listen; no need to open enclosure. Contact ES if blower is not running. If any unusual noise or vibration is noticed, turn-off blower and contact ES.

WEEKLY MAINTENANCE

Lubrication

1. Add grease to the two grease fittings until grease begins coming out of relief fittings.

2. Check oil level.
   a. Remove "breather" and oil overflow plugs.
   b. Add oil until it begins coming out of overflow.
      (Use SAE 40 in summer and SAE 30 in winter)

Pressure/vacuum measurements.

Record readings from both the outlet pressure and inlet vacuum gages along with the date.

Miscellaneous

Note any unusual noise or vibration and contact ES.

PERIODIC MAINTENANCE

Change air filter when inlet vacuum exceeds 1.0 PSI. Also contact ES.

BLOWER MAINTENANCE RECORD
SPILL SITE 1
F. E. WARREN AFB, WYOMING

DATE	INLET VACUUM	OUTLET PRESSURE	ADD GREASE ?	ADD OIL ?	COMMENTS